

Site formation processes at Cenjiawan (Nihewan Basin, North China): a case study on the structure of the Early Pleistocene archaeological record in lakeshore environments

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ABSTRACT: Lakeshore environments offer an excellent opportunity to explore how early humans adapted to changing landscapes and environments. The Nihewan fluvio-lacustrine sequence in North China contains one of the densest concentrations of Early Pleistocene Palaeolithic sites outside of Africa. Among these, the Cenjiawan site, dated at 1.1 Ma, draws attention due to the large number of stone tool refits. We present here Cenjiawan's sedimentary context, artefact spatial patterns, size distribution and taphonomic features, which are complemented by an experimental programme to better understand archaeological debitage size patterns, thus enabling a detailed analysis of formation processes at the site. The Cenjiawan assemblage is also interpreted in the light of its geographical and geological context, where a syndimentary fault induced a minor topographic relief across the lacustrine lakeshore. This resulted in a shallow-water setting in the down-thrown hanging wall of the fault compartment, and a fluvial environment in the uplifted footwall. Our results indicate that Cenjiawan, situated in the hanging wall of the fault, underwent minimal disturbance, constituting a remarkable example of optimal preservation of archaeological assemblages in Early Pleistocene lakeshore environments. © 2022 John Wiley & Sons, Ltd.

KEYWORDS: debitage size distribution; Early Pleistocene; lakeshore environment; spatial analysis; stone tool refitting

Introduction

Lakeshore environments are biologically productive areas that offer a broad range of predictable resources and were frequently inhabited by early humans (Isaac *et al.*, 1997a; Leakey, 1971; Potts, 1988). It is generally assumed that sites in lakeshore environments are subjected to more gentle burial processes (Morton, 2004; Pei *et al.*, 2014; Potts, 1982; Sahnouni and Heinzelin, 1998; Sahnouni, 2002; Schick, 1986, 1987) than those in alluvial settings (Isaac, 1983), and thus present favourable conditions for the preservation of archaeological remains.

The study of site formation processes has long been recognised as an essential aspect for interpreting early human behaviour (Benito-Calvo and de la Torre, 2011; de la Torre, 2011; Isaac, 1967; Malinsky-Buller *et al.*, 2011; Morton, 2004; Petraglia and Nash, 1987; Sahnouni, 2002; Schick, 1987, 1992). Because many early Palaeolithic sites are palimpsests caused by a superimposition of biological and physical agents (Cahen and Moeyersons, 1977; de la Torre and Wehr, 2018; Isaac, 1967; Pante, 2010; Petraglia and Potts, 1994; Schiffer, 1972), various geological, spatial and archaeological proxies are used to reconstruct the impact of such agents (de la Torre and Wehr, 2018; de la Torre

et al., 2018, 2019; Hassan, 1978; Isaac, 1967; Pei *et al.*, 2016; Schick, 1984, 1987, 1991; Schiffer, 1972, 1983, 1996).

The study of Early Stone Age site formation processes has received considerable attention since the 1960s, with a series of proxies proposed to assess hydraulic disturbance (de la Torre *et al.*, 2019; Isaac, 1967; Schick, 1984, 1987, 1991). Most of those efforts, however, have focused on African sequences and, more recently, European assemblages (García-Moreno *et al.*, 2016, 2020; Peters and van Kolfschoten, 2020), while early Palaeolithic records elsewhere have received less attention. In this context, the Early Pleistocene sites located in lakeshore depositional environments at the Nihewan Basin provide an excellent opportunity to explore human behavioural adaptations in North China through testing the agents involved in the formation of assemblages.

The Nihewan Basin of North China is located in the north-eastern part of Shanxi province and the northwestern part of Hebei province, and is filled with Pliocene to Holocene fluvio-lacustrine and aeolian deposits (Barbour, 1924; Deng *et al.*, 2008, 2019). The eastern margin of the basin contains one of the densest concentrations of Early Pleistocene Palaeolithic sites (Fig. 1) outside of Africa, and is of paramount importance in our understanding of human adaptations in Early Pleistocene Asia (Antón and Swisher, 2004; Ao *et al.*, 2010a, 2013a; Bar-Yosef and Belfer-Cohen, 2001; Deng *et al.*, 2007, 2008; Dennell, 2009; Gao *et al.*, 2005; Pei *et al.*, 2017, 2019; Yang *et al.*, 2017, 2020a; 2020b, 2021; Zhu *et al.*, 2001, 2003, 2004, 2008).

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selected the site of Cenjiawan (CJW). CJW (*ca.* 1.1 Ma) is located in the hanging wall of the fault compartment and contains one of the largest lithic assemblages (Guan *et al.*, 2016; Wang *et al.*, 2006; Yang *et al.*, 2021), and the highest refit ratio, amongst all early Palaeolithic sites in the Nihewan Basin. Given the unparalleled quality of the CJW archaeological record, this site offers an excellent opportunity to reflect upon assemblage formation processes in the Nihewan Basin, evaluate the potential influence of tectonics in different fault settings, and reconstruct the effect of natural agents in Early Pleistocene archaeological assemblages. Such topics will be explored in this paper through the analysis of its sedimentary context, artefact spatial patterns, and stone tool features such as edge roundness, size distribution, and refit sets at CJW, one of the most relevant early Palaeolithic sites in Asia.

Site background

Geology and chronostratigraphy

The Nihewan Basin is a down-faulted basin situated between the Inner Mongolian Plateau and the North China Plain (Deng *et al.*, 2019; Pei *et al.*, 2019) (Fig. 1A–B). It is well known for its extensive late Cenozoic fluvio-lacustrine deposits spanning from the Late Pliocene to the late Middle/Upper Pleistocene (Deng *et al.*, 2019; Nian *et al.*, 2014; Zhao *et al.*, 2010), alongside reliably constrained geochronology, abundant archaeological sites, and the palaeontological significance of the so-called Nihewan fauna (*sensu lato*) (Ao *et al.*, 2010b, 2013b; Deng *et al.*, 2006, 2007; Qiu, 2000; Schick *et al.*, 1991; Teilhard de Chardin and Piveteau, 1930; Zhou *et al.*, 1991; Zhu *et al.*, 2001, 2004) (Fig. 1C). These thick and continuous deposits were eroded by the Sanggan River and its tributaries after the Nihewan palaeolake dried out in the Late Pleistocene

(Ji and Wang, 2017). The sedimentary exposures are more than 90 m in thickness at the northeastern margin of the Nihewan Basin, covering an area of circa 20 km². Current geochronological and archaeological research shows that early hominins may have occupied the Nihewan Basin from 1.66 Ma (Zhu *et al.*, 2004) to the Late Pleistocene (Liu *et al.*, 2013; Pei *et al.*, 2019; Schick *et al.*, 1991; Shen and Qi, 2004; Shen *et al.*, 2011).

The CJW Palaeolithic site (41°13'21"N, 114°40'17"E, 869.9 m a.s.l.) is located about 150 m south of the CJW village, circa 1 km north of the well-known site of Donggutuo (Jia *et al.*, 2019; Yang *et al.*, 2017), and 500 m east of Majuangou, the earliest archaeological site in Nihewan (Zhu *et al.*, 2004) (Fig. 1C, D).

The lacustrine sequence represented in the CJW stratigraphy is 28 m thick, and mainly consists of interbedded silty clay/sand strata. The CJW archaeological layer is positioned within the upper segment of a reverse polarity magnetozone bounded by the Olduvai and Jaramillo subchrons, immediately posterior to the Punaruu geomagnetic excursion (Wang *et al.*, 2006), which has an ⁴⁰Ar/³⁹Ar age of 1.105 ± 0.005 Ma (Singer *et al.*, 1999; Yang *et al.*, 2021). The stratigraphic profile exposed at the CJW excavation area is about 5.5 m in thickness and consists of 10 stratigraphic layers (Fig. 2). The archaeological material is contained within a 30–40 cm unit embedded in the lower part of Layer 8 (Fig. 2).

Materials

CJW was discovered in 1984, and four subsequent excavations (Fig. 1E) were conducted by the Institute of Cultural Relics of Hebei Province between 1986 and 1996 (Xie and Cheng, 1990; Xie and Li, 1993). In 2019, we undertook further excavations (Fig. 1E) to collect geological and archaeological

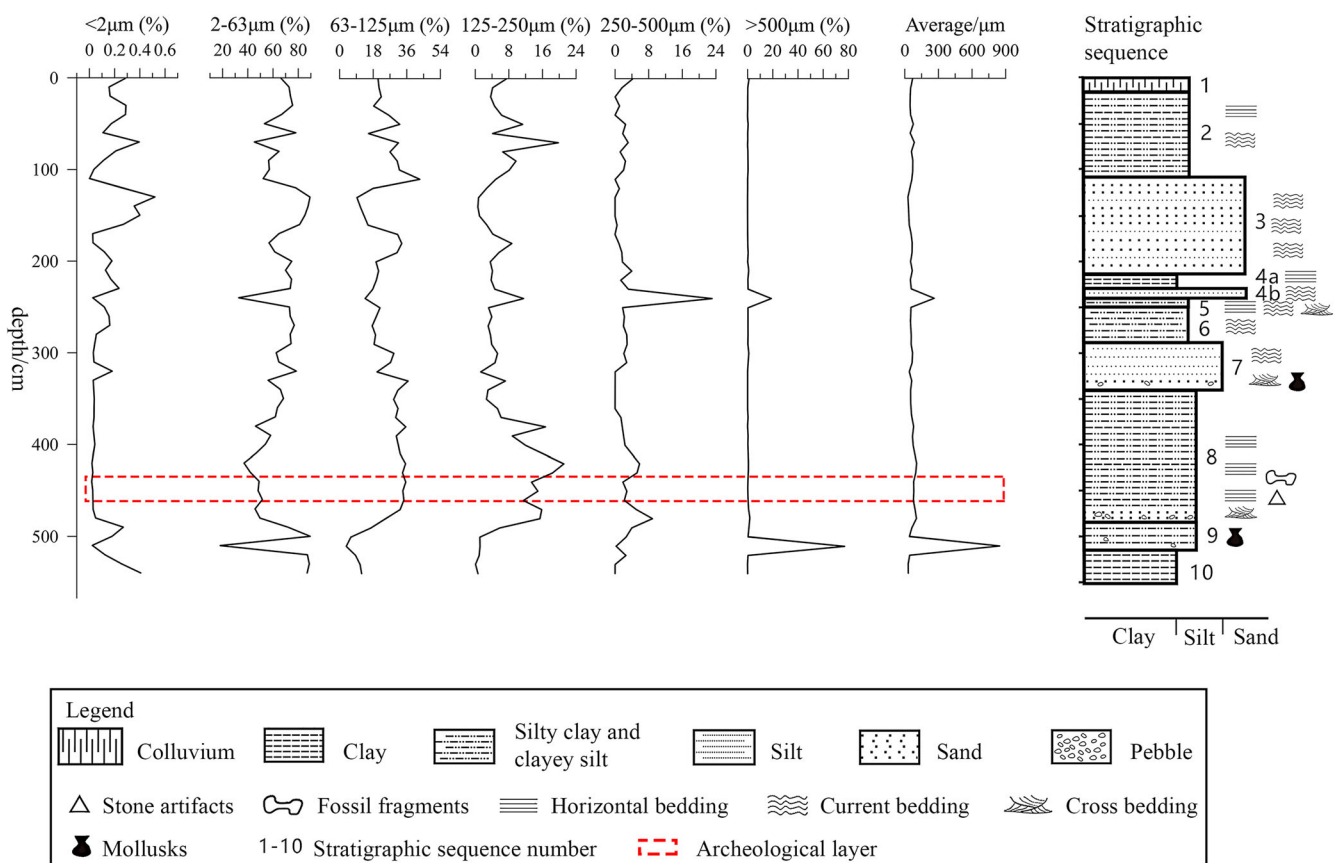


Figure 2. Grain-size analysis results from the Cenjiawan stratigraphic profile. [Color figure can be viewed at wileyonlinelibrary.com]

information. Very few lithic artefacts (nine pieces) were found across 40 m² during the latest fieldwork onsite, suggesting that the main archaeological cluster at CJW has now been fully excavated.

Previous studies reported a total of 1625 lithic artefacts at CJW (Guan *et al.*, 2016; Yang *et al.*, 2021), although small debris were not included in the analyses. In this study, we re-examined all the lithics, with our reanalysis of the assemblage expanding the sample size to 2015 stone tools. We identified six raw materials: chert, siliceous dolomite, siliceous limestone, brecciated chert, quartz and lava. Chert amounts to 72.2% of the whole assemblage and thus is the main raw material at CJW. We have also been able to position 1318 items spatially, of which 713 are lithics and 605 fossil remains. Excluding the first field season (Xie and Cheng, 1990), remains found during the rest of the excavations were mapped, all materials collected, and sediments sieved. A total of 152 refit sets (618 refitted artefacts) were analysed for this study, which constituted a refit ratio of 34.6% for lithic artefacts >1 cm. CJW fossils are heavily fragmented and poorly preserved, and therefore their zooarchaeological characteristics are not considered in this study, although their spatial features will be discussed. Therefore, this study mainly focuses on the spatial and taphonomic data provided by the lithic assemblage.

Methods

Magnetic susceptibility results (Wang *et al.*, 2006) suggest that the CJW sequence has preserved its original sedimentary features. Thus, during the 2019 field season we collected 55 sediment samples at 10 cm intervals from the CJW section to explore further the depositional context of the site. Sediment grain size analysis was measured using a Mastersizer 2000 laser particle size analyser at the Institute of Geology, Chinese Academy of Geological Sciences, which has a repeated measuring error of <2% (Liu *et al.*, 2016).

Artefact edge roundness is a sensitive indicator of fluvial disturbance (Bustos-Pérez *et al.*, 2019; de la Torre and Wehr, 2018; Petraglia and Potts, 1994; Shea, 1999). In this study, four stages (fresh, slight, medium and severe) of edge roundness were employed (de la Torre and Wehr, 2018) to assess the intensity of water action over the assemblage.

Debitage size patterns are an important proxy in assessing fluvial disturbance at Palaeolithic open-air sites (Bertran *et al.*, 2012; de la Torre *et al.*, 2018; Petraglia and Potts, 1994; Schick, 1984, 1987; Sitzia *et al.*, 2012). A comparison of the proportion of smalldebitage (<2 cm) and artefact size curves between archaeological and experimental datasets provides particularly accurate estimates of the integrity of archaeological assemblages (Bertran *et al.*, 2012; de la Torre *et al.*, 2018; Schick, 1986). However, artefact size distributions may be influenced by various factors even in pristine assemblages, including raw material type and knapping techniques, among others (Bertran *et al.*, 2012). To address these limitations in our experiments, we collected four blocks of chert from the CJW area, which were flaked by the first author. Experimental flaking was carried out employing the knapping scheme most commonly observed in the CJW assemblage, namely a multifacial reduction aimed at producing as many flakes as possible. All experimental assemblages were sieved with a 5 mm mesh aperture, with the length of all products remaining in the sieve measured individually. In total, 1392 artefacts were produced experimentally and analysed for the present study.

Except for the distribution patterns and refit lines of the 20 refit sets from the 1992 field season (Xie and Li, 1995), no

spatial analysis has ever been published for the CJW assemblage. However, the spatial distribution and clustering dynamics are crucial to determine post-depositional disturbance (Cahen and Moeyersons, 1977; de la Torre and Wehr, 2018; Sánchez-Romero *et al.*, 2022; Schick, 1986, 1987). Previous studies have shown that the smaller fraction of lithic assemblages is more likely to be redistributed by hydraulic action (Petraglia and Potts, 1994; Schick, 1987, 1991), while large and heavy artefacts lag behind. From this perspective, we spatially analysed the horizontal distribution of different size and weight classes of the CJW lithic artefacts. In this study, we also produced horizontal and vertical kernel density maps to investigate spatial patterns of the CJW assemblage.

Refitting analysis has long been regarded as a key index in assessing site formation disturbance (Cziesla, 1990; de la Torre *et al.*, 2019; Hofman, 1981, 1986; Villa, 1982, 1991). Prior to our study, 608 artefacts had been found to refit in the CJW assemblage. We added over 150 hours more to the refitting efforts, finding 10 new conjoining artefacts. Standard refitting types (Cziesla, 1990; de la Torre *et al.*, 2012, 2019) were synthesised into two groups to facilitate comparisons. In the first type (refit lines between conjoining detached artefacts), we included refit lines between dorsal–ventral refits, transverse and longitudinal refits. In the second type of refit lines (products to core), lines connect cores to all corresponding products. Horizontal distances were calculated for the entire refit collection, whereas the vertical distance and direction between conjoining artefacts were calculated separately for the 1992 and 1994 field seasons, due to the different altitude coordinate system used in each excavation. Sets with more than five conjoining pieces were mapped to investigate their spatial distribution patterns.

Results

Grain-size analysis

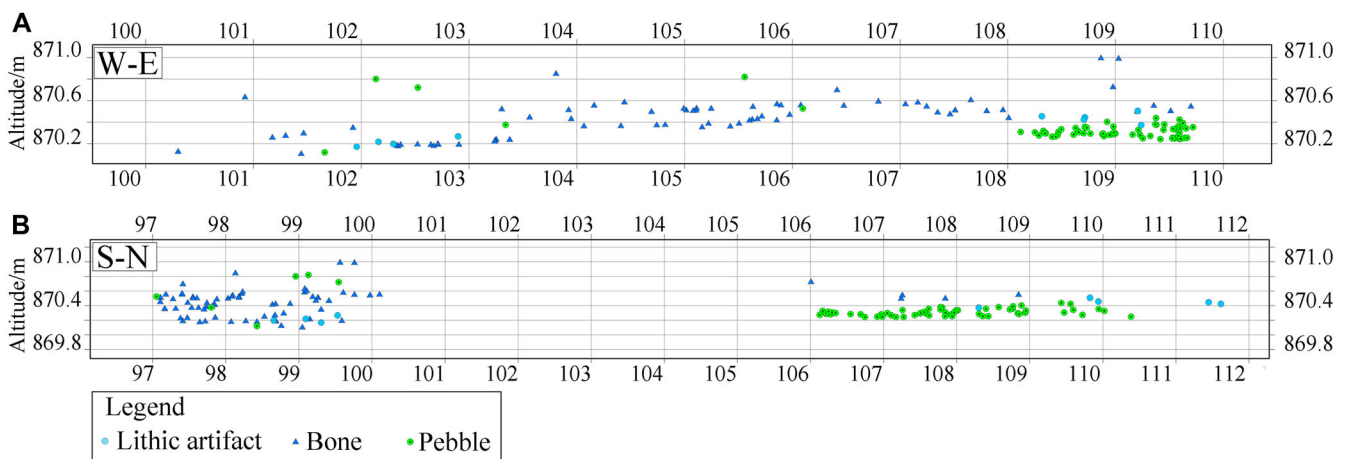
The 5 m thick stratigraphic profile exposed at CJW (Fig. 2) is primarily composed of silt (2–63 µm) and very fine sand (63–125 µm) (Table 1, Fig. 2). Horizontal and current beddings were identified within the lacustrine sequence. This indicates a predominance of gentle water velocity during the deposition, although relatively high-energy flow also occurred, as testified by the small-scale cross-bedding in the bottom of layers 9, 7 and 5. In addition, during our 2019 field season we reported a coarser-grained deposit below the archaeological layer that contained small pebbles (Fig. 3), which indicates a relatively higher energy flow before the deposition of the fossil and artefact remains. The archaeological layer mainly consists of silt (48.58%) and very fine sand (34.09%) (Table 1), suggesting a slow depositional environment during the formation of the archaeological assemblage, even though horizontal bedding is also observed. Overall, the analysis of the sedimentary matrix indicates a fine-grained deposition, primarily of silt in shallow lake margins, with no sedimentary evidence of high-energy depositional events during the formation of the archaeological assemblage.

Roundness

Roundness was analysed in a sample of 2010 lithic artefacts, which excluded pounded and unmodified pieces (*sensu* Isaac *et al.*, 1997b). Most artefacts are in a fresh condition ($n = 1960$; 97.5%), with only a small number of artefacts showing slight ($n = 49$; 2.44%) and medium ($n = 1$, 0.05%) roundness; no artefacts present heavy abrasion. In terms of raw materials, all

Table 1. Grain-size distribution of the Cenjiawan stratigraphic sequence.

Grain size (%): Layer↓	Clay <2 µm	Silt 2–63 µm	Very fine sand 63–125 µm	Fine sand 125–250 µm	Medium-sized sand 250–500 µm	Large than coarse sand >500 µm	Average size µm
1	0.22	69.44	20.86	5.81	2.93	0.72	62.06
2	0.2	63.47	26.27	8.23	1.53	0.2	60.76
3	0.21	73.15	22.32	3.55	0.88	0.19	50.17
4	0.2	74.22	18.75	4.23	2.27	0.32	55.23
5	0.03	32.76	13.63	11.53	23.11	18.94	264.81
6	0.15	74.51	19.62	3.4	2.01	0.31	53.47
7	0.06	68.26	25.16	4.37	1.75	0.4	58.84
8	0.03	52.63	32.64	11.9	2.48	0.32	76.32
Archaeological layer	0.03	48.58	34.09	13.91	2.99	0.4	82.3
9	0.13	57.3	12.67	5.89	3.94	20.07	264.06
10	0.26	87.71	10.49	0.55	0.87	0.1	36.06

**Figure 3.** Cross-section of small pebbles in the 2019 excavation at Cenjiawan. (A) east–west cross-section; (B) north–south cross-section. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1002/jqs.3487)]

the quartz, siliceous limestone and brecciated chert, and 99.6% of chert are in a fresh condition. Only a small proportion of siliceous dolomite ($n = 44$; 25.14% of this raw material) presents slight abrasions. Given the softer structure of siliceous dolomite, edge roundness in this raw material was most likely caused by chemical weathering, rather than mechanical rounding.

Size distribution

A total of 2011 lithics were included in the debitage size distribution analysis, which only excluded unmodified pieces. The mean length is 20.83 mm (SD = 10.38 mm) and Fig. 4A shows the dominance of the 10–19 mm length class, which contains 41.67% ($n = 838$) of the sample. The proportion of lithic pieces with length <5 mm is negligible ($n = 2$, 0.10%), while artefacts less than 20 mm long constitute 52.71% ($n = 1060$) of the entire sample. Lithic artefacts with a length of ≥ 50 mm are scarce ($n = 50$, 2.49%), and only four (0.20%) artefacts are larger than 90 mm. The mean artefact weight is 7.27 g (SD = 82.8 g), but stone tools peak at the <2 g class, which constitutes 59.87% ($n = 1204$) of all artefacts (Fig. 4B).

Fig. 4C shows that, except for siliceous limestone ($n = 17$) and lava ($n = 5$), whose metric disparities are probably explained by their small samples, all raw materials present a similar size distribution. Artefact lengths peak at the 10–19 mm class, with relative frequencies ranging between 36.36% (siliceous dolomite) and 53.57% (quartz).

Taking into consideration the similar size distribution of most rock types, as well as the predominance of chert across all size ranges in the archaeological assemblage (Fig. 4C), the comparison of the CJW debitage size distributions with experimental data obtained from local chert may provide valuable insights.

Artefact lengths in the four experiments with local chert peak at the 10–19 mm class (Fig. 4D), with relative frequencies oscillating between 45% (experiment E1) and 48% (experiment E3). When considering pieces with a length ≥ 5 mm, an average of 75% (ranging between 67% and 79%) of all experimental artefacts are smaller than 20 mm (Table 2).

The debitage length curve of both the CJW assemblage and all our experiments presents a unimodal, positively skewed shape, which peaks at the 10–19 mm length class, although the 5–9 mm class is much smaller than in all the experiments considered here (Fig. 4D). Overall, the percentage of the CJW artefacts that are shorter than 20 mm is 56.41%, which is smaller than in all experiments (Table 2) and presents statistically significant differences ($\chi^2(1) = 174.340$, $p = 0.000$) from our experimental data (75%).

Spatial analysis

The horizontal distribution of findings at CJW (Fig. 5A) shows distinct clustering. The densest concentration is immediately to the west of the 1986 excavation (Fig. 5A). Taking into consideration the large number of lithic artefacts ($n = 897$)

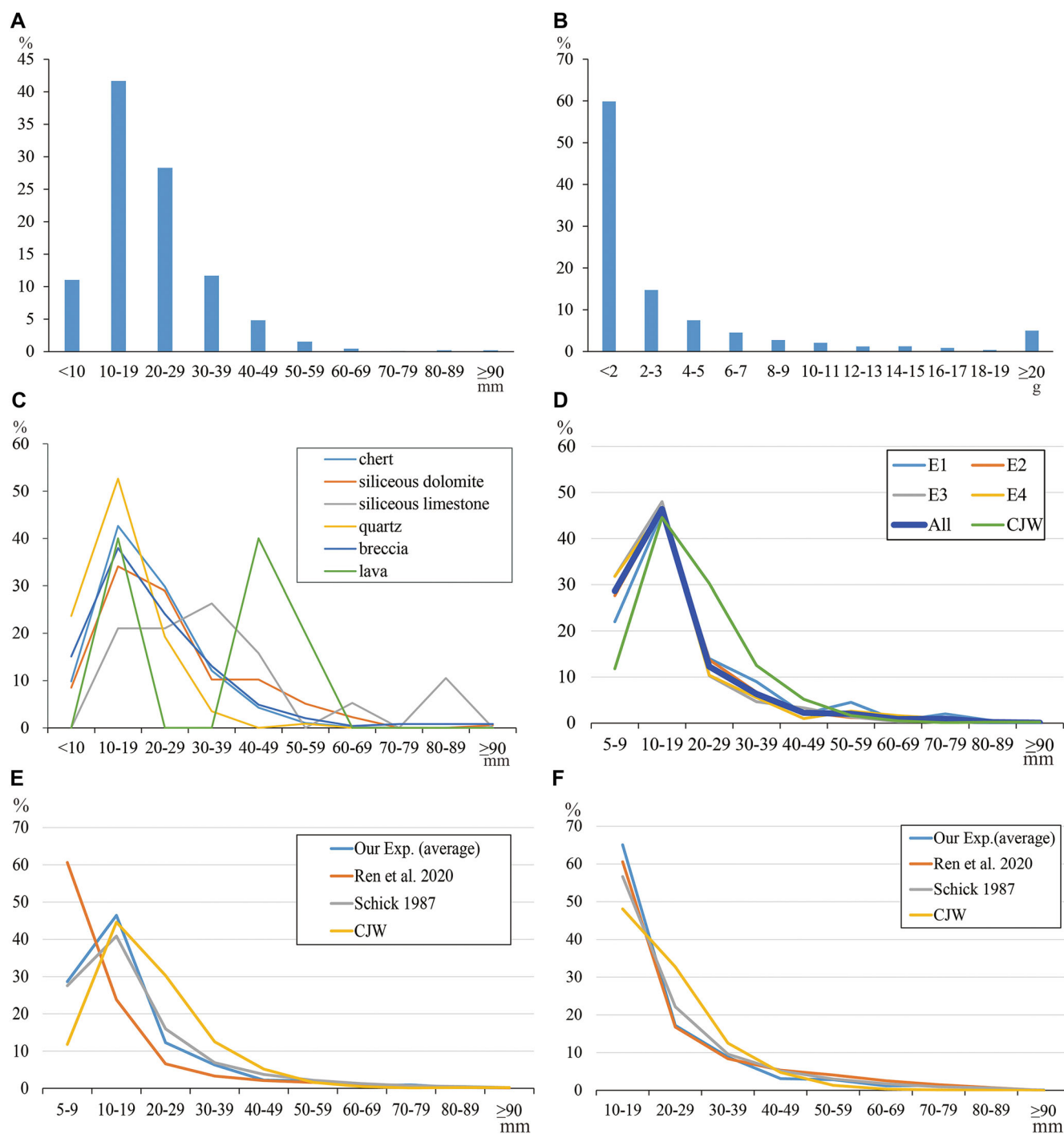


Figure 4. Dimensions of artefacts in Cenjiawan and length comparison between Cenjiawan and experimental data. (A) length distribution (10 mm intervals); (B) weight distribution (2 g intervals); (C) length distribution of different raw materials (10 mm intervals); (D) debitage size distributions of experiments produced in this study; (E–F) Compared debitage size distribution of experimental data and the Cenjiawan assemblage: (E) length > 5 mm; (F) length > 10 mm. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.com)]

unearthed in 1986, it is safe to assume that the densest cluster in Fig. 5A extended further to the east. Both lithics and fossils show their densest concentration in the main cluster (Figs 5B and 6C), with a smaller cluster of lithics to the west, and bones to the north.

The potential influence of low-energy sheet wash processes on the spatial configuration of CJW was investigated with horizontal and vertical distribution maps per length and weight classes of artefacts. Fig. 6 shows that all classes of artefacts, regardless of length or weight, are concentrated in the main horizontal cluster. Additionally, the horizontal distribution of

smaller artefacts is uniform, with no sorting patterns that could indicate water rearrangement.

Regarding the vertical distribution, cross-sections in Fig. 7 show that archaeological remains are mostly clustered in a 30–40 cm thick unit. Nonetheless, our field observations indicate that the stratigraphic layers follow a west-to-east slope (Fig. 3A). Therefore, considering the large excavation area (up to 104 m² in 1994) (Fig. 1E) and the west-to-east inclination of the assemblage, it is to be expected that the vertical distribution of archaeological remains appears to be thicker in cross-section. When lithic and fossil assemblages are plotted

Table 2. Debitage length distribution of experimental sets and the Cenjiawan archaeological assemblage.

	5–9 mm		10–19 mm		20–29 mm		30–39 mm		40–49 mm		50–59 mm		60–69 mm		70–79 mm		80–89 mm		≥90 mm		Total		
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	
E1	44	22.00	91	45.50	28	14.00	18	9.00	4	2.00	9	4.50	1	0.50	4	2.00	1	0.50	0	0.00			200
E2	161	27.66	268	46.05	80	13.75	39	6.70	14	2.41	7	1.20	5	0.86	5	0.86	2	0.34	1	0.17			582
E3	96	31.79	145	48.01	31	10.26	14	4.64	10	3.31	4	1.32	1	0.33	1	0.33	0	0.00	0	0.00			302
E4	98	31.82	142	46.10	32	10.39	17	5.52	3	0.97	8	2.60	5	1.62	3	0.97	0	0.00	0	0.00			308
All experiments	399	28.66	646	46.41	171	12.28	88	6.32	31	2.23	28	2.01	12	0.86	13	0.93	3	0.22	1	0.07			1392
Cenjiawan	222	11.81	838	44.60	569	30.28	235	12.51	97	5.16	31	1.65	9	0.48	2	0.11	4	0.21	4	0.21			2011

separately, the lithic artefacts are vertically more concentrated than the fossils.

Refitting

A total of 152 refit sets were identified at CJW, which amount to 618 stone tools (Table 3). If the entire lithic assemblage ($n = 2010$, except unmodified pieces and pounded pieces) is considered, the proportion of refitted material is 30.74%. This proportion is even higher (34.6%, $n = 1786$) when only pieces larger than 10 mm are taken into account. Most refit sets consist of two lithic pieces (48%), while eight refit sets (5.3%) contain more than 10 pieces, and the largest up to 47 artefacts (Fig. 8). The average dimension of refitting pieces is 28.6 mm in length (SD = 11.2 mm) with a mean weight of 8.56 g (SD = 15.1 g).

Our reconstruction of the excavation process at CJW enabled us to document the spatial position of 23 refit sets (78 refitted artefacts). Fig. 9A shows that the refit sets are mainly located in the two clusters of lithics discussed in the previous section. While some refit lines indicate a connection between the two clusters, most refit sets are restricted to the area of each concentration. This is particularly obvious in the case of core–product connections, which are self-contained in each cluster (Fig. 9B).

A total of 51 refit lines between conjoining detached artefacts are shown in Fig. 9A. The average horizontal distance of all refit lines between conjoining detached artefacts is 146 cm (Table 4), although most are shorter than 100 cm (45%), with a smaller proportion (25%) of refit lines longer than 200 cm (Fig. 10A). A visual inspection of the horizontal map of refits sets (Fig. 9A) suggests a bimodal distribution for the direction of refit lines, with a northeast–southwest trend connecting the two artefact clusters, and a north–south trend within the main lithic cluster. This latter pattern is supported by the strong north–south preference shown in the Rose diagram (Fig. 10C).

In terms of product-to-core refit lines ($n = 30$), the mean horizontal distance is 127 cm (Table 4), which is similar to that of refit lines between conjoining detached artefacts. Thirty percent of all refit line distances between products to cores are shorter than 50 cm, while 60% are longer than 100 cm (Fig. 10B). The direction of most product-to-core refit lines ranges between 345° and 360° (Fig. 10D), hence presenting a strongly preferred trend as in the case of refit lines between conjoining detached artefacts.

Fig. 9C and D shows the vertical connection of refit sets. The average vertical distance of refitted lines is 5.8 cm, with a minimum distance of less than 1 cm, and a maximum of 24.5 cm (Table 4). Refitting artefacts that are vertically separated by less than 15 cm was found to be at 90.6%, with 56.2% of them separated by less than 5 cm (Fig. 10E).

With regards to refit sets containing a larger number of pieces (e.g. NS38, NS65, NS72, NS112, NS125), Fig. 11 shows that most are concentrated in very restricted areas, while only a couple (NS7, NS8) are scattered across a wider range of the excavation surface. Interestingly, both refit sets NS7 and NS8 belong to the same raw material nodule, which is characterised by frequent internal flaws and is prone to uncontrolled fracturing during knapping.

Discussion

Evaluating taphonomic processes at Cenjiawan

Except for some siliceous dolomite artefacts that may have been affected by chemical weathering, nearly all the CJW

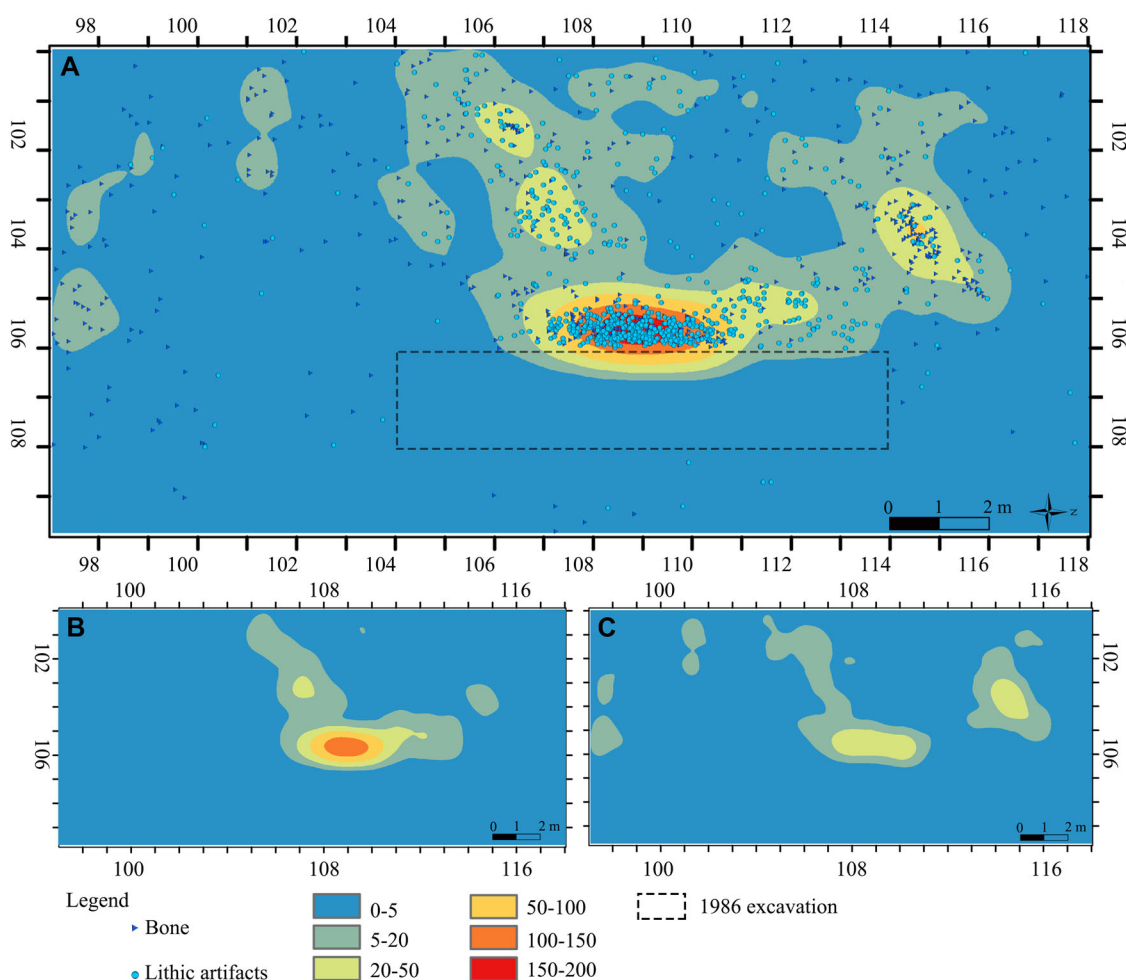


Figure 5. Density map of archaeological remains in Cenjiawan. (A) entire assemblage; (B) lithic artefacts; (C) bones. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1002/jqs.3487)]

stone tools are in a fresh condition, which suggests the assemblage did not undergo significant transport.

Our grain-size analysis indicates that the archaeological layer at CJW mainly consists of silty clay and clayed silt, typical of lake margins where low-energy sheet flow predominates. Wang *et al.* (2006) measured the anisotropy of magnetic susceptibility at the CJW lacustrine sequence, and their results indicated that the deposits preserve their original sedimentary features. However, the presence of abundant pebbles and coarse sands under the archaeological layer on the eastern part of the site indicates that higher-energy water flow also operated in the area prior to the deposition of the archaeological remains.

The comparison of debitage size distributions suggests significant differences between our experiments and the CJW assemblage. To strengthen comparisons, we also considered two additional experimental databases (Fig. 4E). Experiments by Ren *et al.* (2020) were based on the local chert in Nihewan Basin, which is similar to the raw material used in our experiments, while Schick's (1992) used essentially basalt, quartz and chert.

In the experiments by Ren *et al.* (2020), the 5–10 mm length class accounts for up to 63%, differing significantly from Schick's results (Fig. 4E). Likewise, their proportion of debitage in the <20 mm length class is around 84%, which is also higher than in Schick's experiments. Such discrepancies are attributed by Ren *et al.* (2020) to the poor quality of the local chert, as Nihewan chert often exhibits internal flaws, fractures and brecciated structures, which increase the fragmentation ratio during knapping processes

(Guan *et al.*, 2016; Pei and Hou, 2002; Pei *et al.*, 2017; Schick *et al.*, 1991).

Our experimental data, however, resemble Schick's (1987) more than the results obtained by Ren *et al.* (2020) (Fig. 4E). Dominance of the 10–19 mm length class is observed in both Schick's and (68%) and our experiments (75%), while Ren *et al.* (2020)'s curves peak at 5–9 mm (84%). The percentage of CJW artefacts <20 mm is also significantly lower than the experimental databases of Ren *et al.* ($\chi^2(1) = 984.539$, $p = 0.000$) and Schick ($\chi^2(1) = 161.384$, $p = 0.000$).

Taking into account that sediments were not sieved during the most productive excavation at CJW (1986 field season), it is likely that a significant number of small debris went uncollected. Thus, to refine the comparison, we recalculated the size distribution of ≥ 10 mm debitage from both archaeological and experimental assemblages (Fig. 4F), after which the proportion of archaeological debitage in the 10–19 mm class is still significantly lower in our experiments ($\chi^2(1) = 85.114$, $p = 0.000$) than in Ren *et al.*'s ($\chi^2(1) = 91.476$, $p = 0.000$) and Schick's results ($\chi^2(1) = 46.180$, $p = 0.000$). In short, the CJW lithic artefact size curve shows a similar trend to that of the experimental data, with the exception of the <20 mm pieces where the proportion at CJW is lower than in the experimental data. This could indicate the action of gentle lamellar sheet water flow that removed the smaller fraction of the archaeological assemblage.

Our spatial analysis indicates the presence of a dense cluster of artefacts, accompanied by two smaller concentrations. The largest cluster contains mostly lithics and gathered all types of

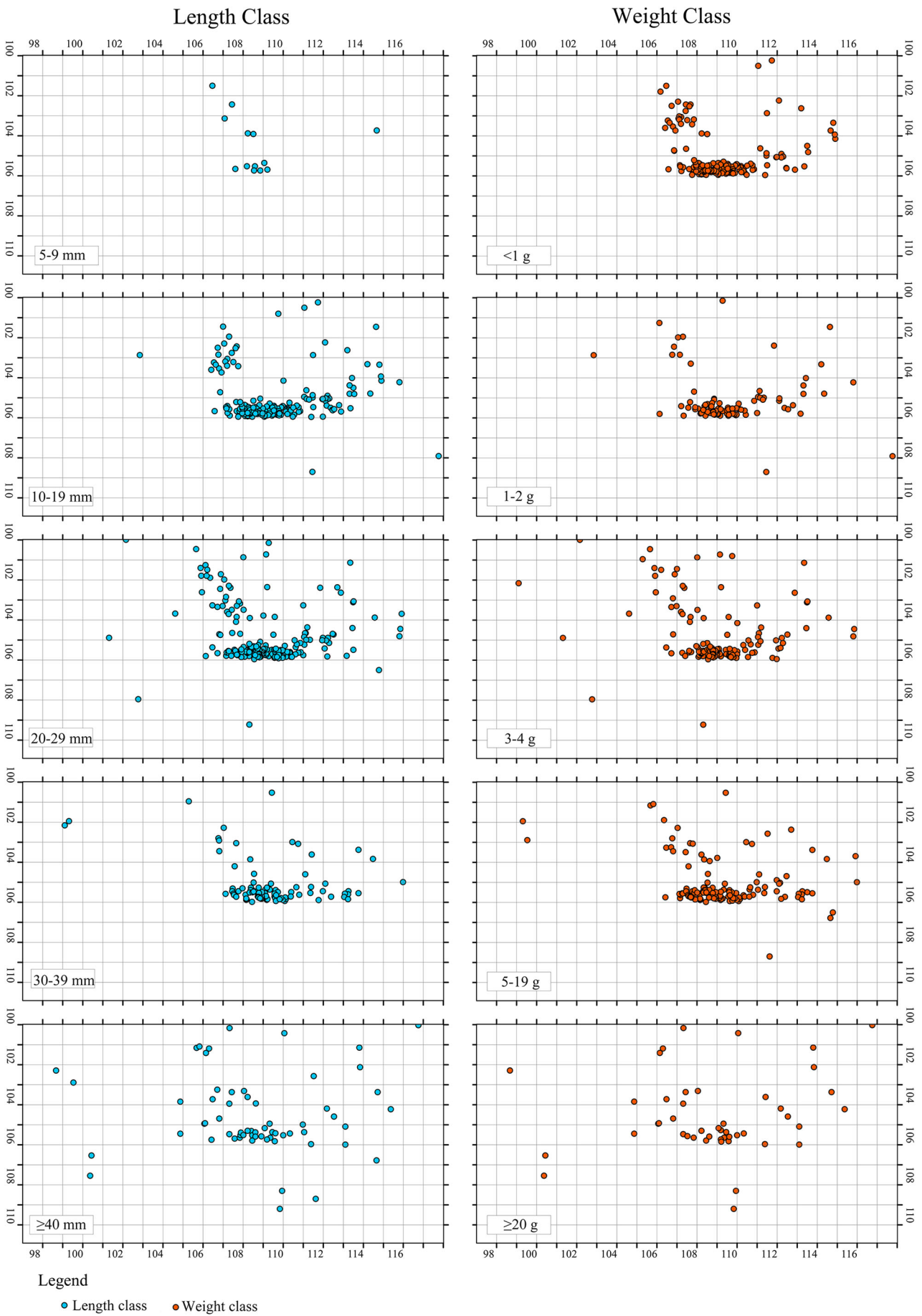


Figure 6. Horizontal distribution of lithic artefacts per length (left) and weight (right) classes. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1002/jqs.3487)]

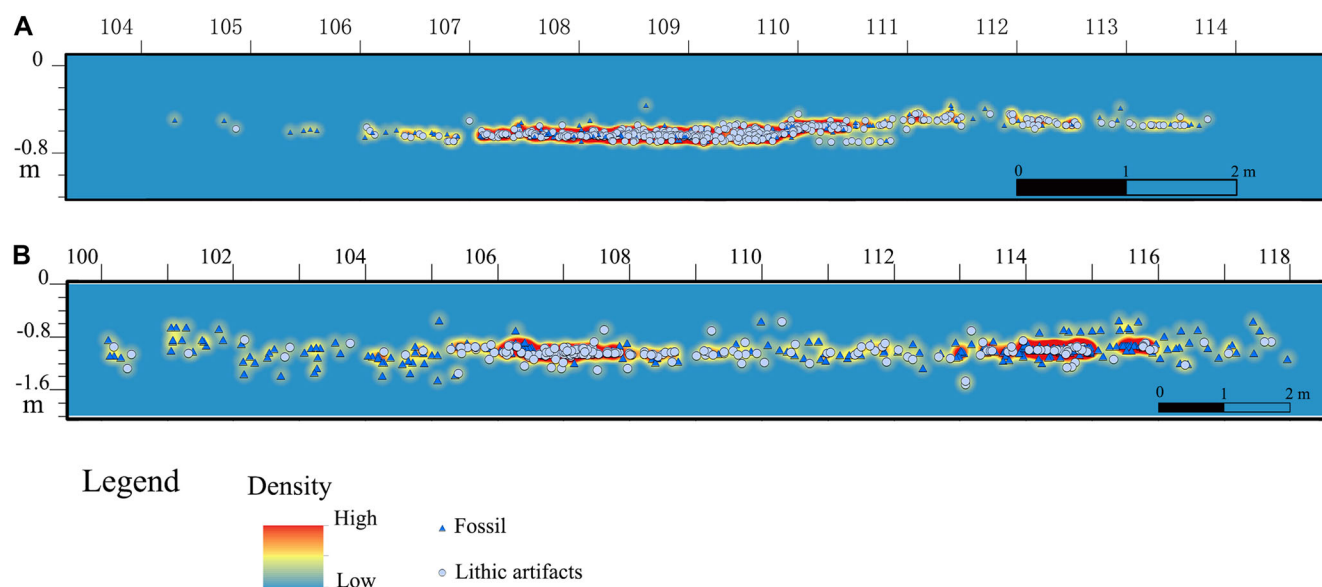


Figure 7. Vertical distribution of all archaeological remains in the 1992 (A) and 1994 (B) excavations, which are plotted separately due to their different altitude coordinate systems. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1002/jqs.3487)]

Table 3. Breakdown of refit sets in the Cenjiawan assemblage.

Number of conjoining artefacts in refit sets	n	%
2	73	48
3	26	17.1
4	14	9.2
5	15	9.9
6	4	2.6
7	4	2.6
8	2	1.3
9	6	3.9
10	1	0.7
11	1	0.7
12	2	1.3
14	1	0.7
16	1	0.7
19	1	0.7
47	1	0.7
ALL	152	100

artefacts, including cores, flakes, retouched tools and fragments. Whereas one of the smaller clusters is also dominated by stone tools, the other mostly includes fossil fragments (see Fig. 5). The interpretation of such patterning is not straightforward: on the one hand it could be proposed that, had those clusters been formed by natural processes, no segregation would be expected between the fossil and lithic assemblages. On the other hand it may also be proposed that each cluster corresponds to separate events of deposition, in which case their attribution to a single archaeological level would not necessarily indicate a contextual association between the stone tools and fossil remains.

The vertical distribution may also indicate separate formation histories for the stone tools and fossils; while all lithics are concentrated in a narrow vertical span of around 30 cm, fossil fragments appear more scattered vertically. In any case, the spatial configuration of the archaeological remains does not exhibit, overall, trends produced by fluvial modification as observed in simulations of hydraulic disturbance (Byers *et al.*, 2015; Isaac, 1967; Schick, 1986).

The large number of refit sets and refitting ratios also supports limited post-depositional disturbance. The average distance for refit lines between conjoining detached artefacts and product-to-core refit lines is similar (around 1.3 m). The average distance of refit lines at CJW is longer than in experimental contexts where the knapper remains stationary (around 0.5 m) (de la Torre *et al.*, 2019; Newcomer and Sieveking, 1980), even though most CJW conjoining lines are less than 100 cm (Fig. 10A, B).

In summary, the depositional environment, roundness ratios, spatial patterns and refit data all suggest that CJW did not experience high-energy water flow disturbance.

Cenjiawan contributes to the reconstruction of site formation processes at the Nihewan Basin

Fluvio-lacustrine processes are relevant to a significant number of Early Pleistocene archaeological sites in the Nihewan Basin, and recent studies of some early Palaeolithic assemblages (Jia *et al.*, 2019; Pei *et al.*, 2016, 2017) provide comparative evidence for evaluating the CJW site integrity in the context of the Early Pleistocene record for the region.

The role of faulting in the formation of archaeological assemblages has been considered in other palaeoanthropological basins (e.g. Stollhofen and Stanistreet, 2012), but is yet to be assessed in the case of the Nihewan Basin. The Nihewan Basin is a normal faulting-induced intermontane basin (Ao *et al.*, 2010a; Zhu *et al.*, 2001); affected by northwest–southeast tensile stress and faulting, the area gradually sank into a mountain rift and deposited the fluvio-lacustrine sequence known as the Nihewan Formation (Deng *et al.*, 2008; Min and Chi, 2003; Zhou *et al.*, 1991). Early Pleistocene archaeological sites at the Nihewan Basin are mainly positioned in the Cenjiawan Platform (Fig. 1C), located on the northeastern margin of the Nihewan Palaeolake. Early Pleistocene sites are distributed on the two sides of an elongated northeast–southwest normal fault (Fig. 1C). In the northwestern part (down-thrown hanging wall) of the fault, depositional settings shifted from deep to shallow waters constrained by the steep fault plane. In contrast, in the southeastern part of the fault (the uplifted footwall), a gentler slope mediated depositional landscapes that fluctuated between shallow waters and fluvial settings. Transgression–regression cycles of the Nihewan palaeolake should have impacted the

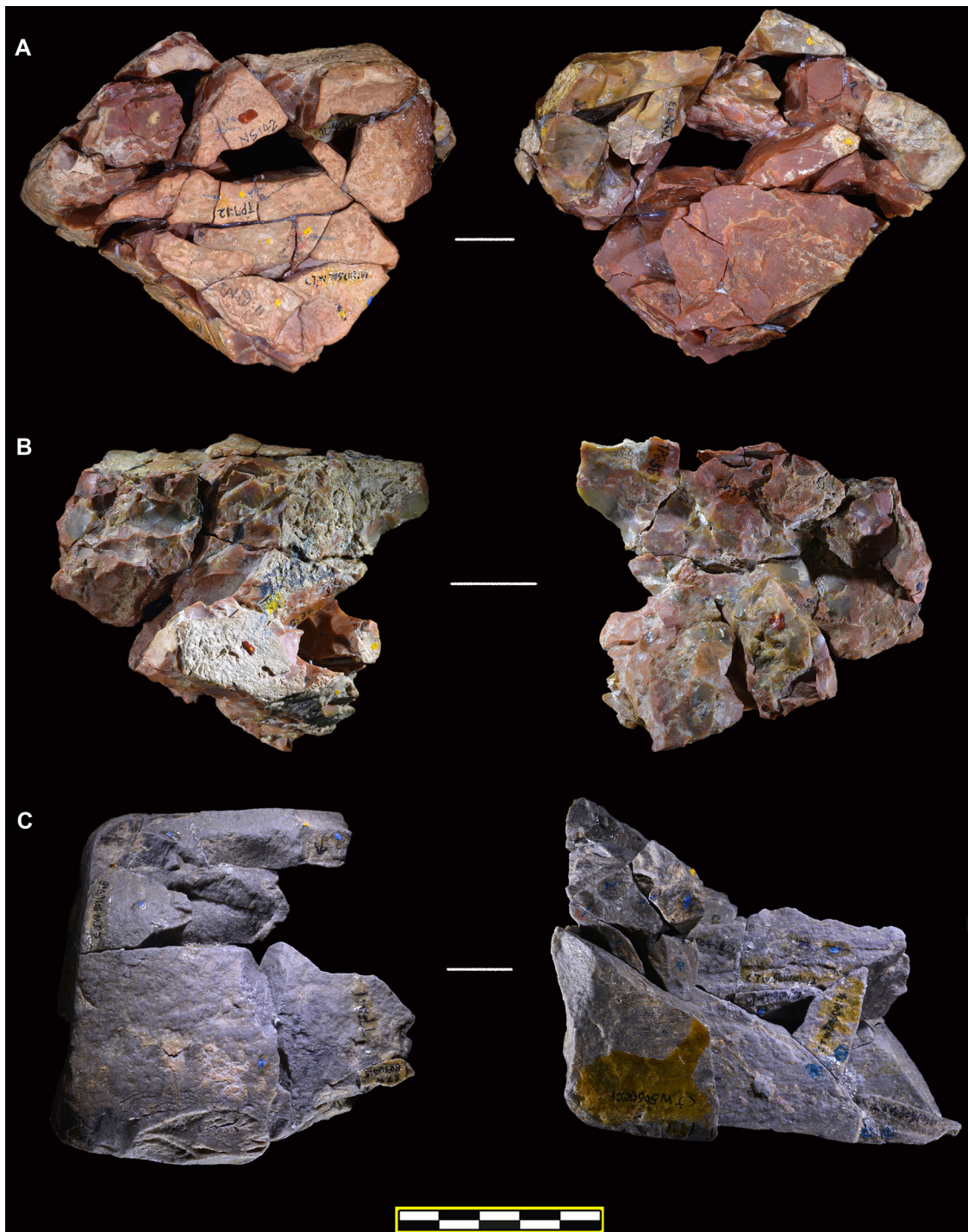


Figure 8. Examples of refit sets from Cenjiawan. (A) NS125 ($n = 47$ pieces); (B) NS38 ($n = 14$ pieces); (C) NS8 ($n = 16$ pieces). [Color figure can be viewed at wileyonlinelibrary.com]

formation of archaeological sites across the two sides of the fault, for which different preservation situations are to be expected according to the fluctuating depositional circumstances.

In the hanging wall, the depositional environment was dominated by deep to shallow marshes and swamps where very fine-grained deposits such as dark clays and marls predominate due to the limited supply of sediment components from the fault plane. This is the setting where sites such as Majuangou (MJG) (Zhu *et al.*, 2004) and CJW (this paper) are located, and which may have been disturbed mostly by laminar flows with little entrainment capability. Although a reconstruction of site formation processes at MJG (Li and Xie, 1998; Zhu *et al.*, 2004) has not yet been conducted, the

gentle deposition dominating this setting is illustrated, for instance, by the preservation of animal footprints and concentration of fossils from single carcasses in lakeshore sediments (Zhu *et al.*, 2004). Our results suggest a high integrity for the archaeological assemblage in CJW as well, which thus could lead to hypothesising an excellent preservation of archaeological sites located in the hanging wall of the fault.

Archaeological assemblages such as Xiaochangliang (XCL), Feiliang (FL), Donggutuo (DGT) and Madigou (MDG) are located in the southeastern part (footwall) of the fault (see again Fig. 1C). This area contains sediments deposited in lakeshore settings such as shallow waters, lake margins,

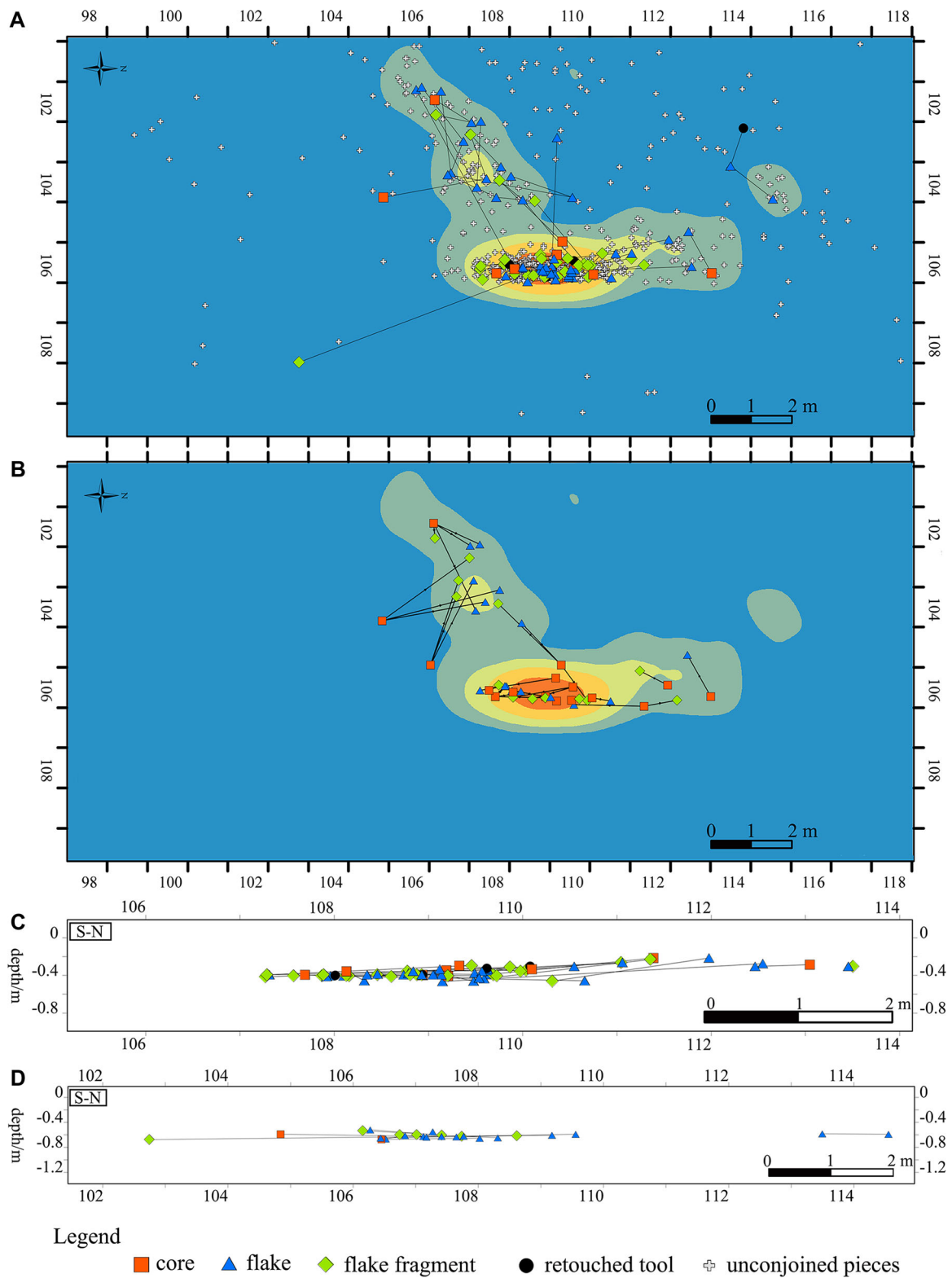


Figure 9. Horizontal and vertical distribution of refit sets in the Cenjiawan assemblage. (A) refit lines between adjoining detached artefacts; (B) refit lines between products to cores; (C) refit sets from the 1992 excavation; (D) refit sets from the 1994 excavation. [Color figure can be viewed at wileyonlinelibrary.com]

laminar flow sandbars, braided stream channels and fluvial floodplains.

The site formation processes at XCL (1.36 Ma) are yet to be systematically investigated, but available studies (Chen *et al.*, 1999; Peterson *et al.*, 2003) report that the archaeological assemblage was deposited in fine-grained sands, and that the fossil assemblages underwent substantial post-depositional disturbance. Pei *et al.* (2017) positioned FL (1.2 Ma) within a wetland setting of the Nihewan palaeolake

margin and suggested that low-energy sheet wash processes may have removed some of the small fractions of the archaeological assemblage, which nonetheless did not alter the original configuration of the site significantly. The main assemblage at MDG (1.2 Ma) (Pei *et al.*, 2016) was formed between the braided stream channel to fluvial floodplains of the palaeolake shore. Pei *et al.* (2016) highlight the relatively low proportion of small lithics at MDG, which may be indicative of high-energy water flows that rearranged the

Table 4. Distance (cm) of refitted artefacts from Cenjiawan.

Horizontal distance	N	(%)	Mean (cm)	Min	Max	
Refit lines between conjoining detached artefacts	All	51	100	145.6	6.08	674
Refit lines between products to cores	All	30	100	127	18	302
Vertical distance of refits	1992	21	64.5	6.5	0.5	24.5
	1994	11	35.5	4.4	0.7	8.5
	All	32	100	5.8	0.5	24.5

assemblage. DGT (1.1 Ma) has yielded the richest Early Pleistocene assemblage in the Nihewan Basin. Jia *et al.* (2019) have proposed that the DGT stratigraphic sequence represents a retrograding event of fine-grained deposits of a shallow-water environment overlying the fluvial channel deposits, in which the lower two archaeological layers (6C and 6D) constitute an alluvial breccia layer with coarser clasts that indicate high-energy water events. On the other hand, the two upper archaeological layers (6A and 6B) at DGT belong to a lake transgression and are preserved in fine silt and clay sediments, thus suggesting lesser disturbance of the original assemblages.

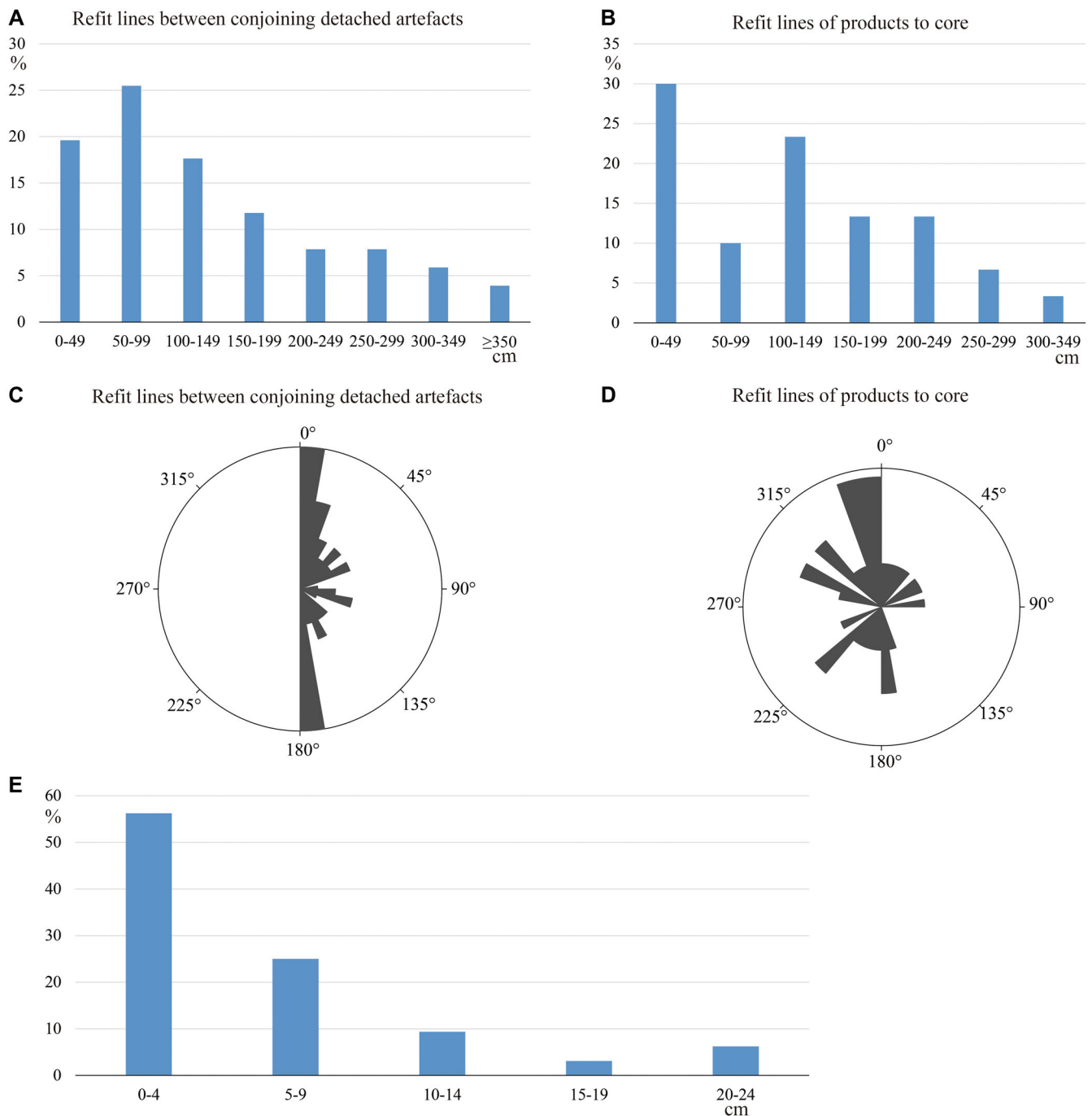


Figure 10. Distance (A–B, E) and orientation (C–D) of refit lines from Cenjiawan. (A) horizontal distance of refit lines between conjoining detached artefacts; (B) horizontal distance of refit lines between products to cores; (C) orientation patterns of refit lines between conjoining detached artefacts; (D) orientation patterns of refit lines between products to cores; (E) vertical distance of refit lines. [Color figure can be viewed at wileyonlinelibrary.com]

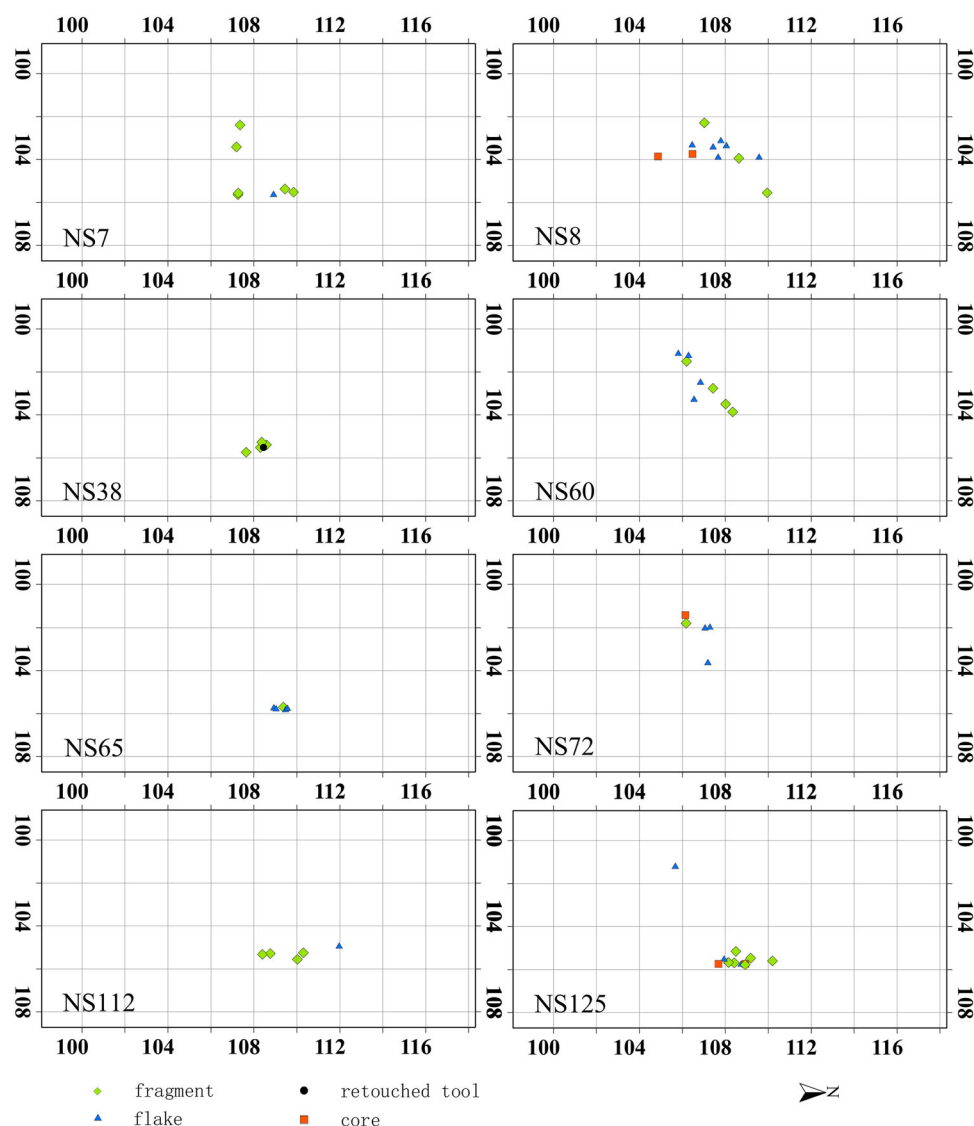


Figure 11. Horizontal distribution of refit sets with more than five conjoining pieces. [Color figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com/doi/10.1002/jqs.3487)]

In summary, from our review of formation processes across existing Early Pleistocene sites in the Nihewan Basin, a novel hypothesis can be proposed; sites deposited in the footwall of the major fault may have experienced more post-depositional disturbance than those in the hanging wall. The significant height difference caused by the Cenjiawan Platform fault may have conditioned different environmental and depositional settings, thus influencing the site formation processes.

Of course, it should be kept in mind that lakeshore environments are complex, and our hypothesis needs to be tested once more systematic studies of post-depositional disturbance are available for the Nihewan sequence, and a more in-depth understanding of the geomorphological features of the Cenjiawan Platform is achieved. In any case, it is clear that the fluvio-lacustrine sequence associated with the eastern margin of the Nihewan palaeolake underwent complex depositional events, and that these may have been largely driven by tectonics which produced a mosaic of topographic and environmental settings. The resulting landscapes should have influenced hominin behavioural patterns and must have had an impact on the formation processes of Early Pleistocene sites across the area. In this context, our results suggest that CJW is one of the best-preserved assemblages in the Early Pleistocene Nihewan sequence and should constitute a

reference for our understanding of site formation processes across this fluvio-lacustrine basin.

Conclusions

The fluvio-lacustrine sequence at the Nihewan Basin constitutes an excellent laboratory to evaluate the formation of Early Pleistocene archaeological assemblages and its relevance for the study of human evolution and behavioural adaptations in East Asia. This paper has studied site formation processes at CJW, one of the most relevant sites in the Nihewan Basin, through a systematic analysis of the archaeological material and its depositional environment, as well as through new experimental data on debitage size distribution aimed at providing a referential framework to assess hydraulic disturbance. Our results indicate that, while there might have been gentle lamellar sheet water flow at CJW, the integrity of the lithic assemblage is relatively high, thus enabling a detailed assessment of hominin behaviour at the site (Guan *et al.*, 2016; Ma, 2021; Yang *et al.*, 2021).

The elongated northeast–southwest synsedimentary normal fault in Nihewan Basin provided different environmental settings for Early Pleistocene sites distributed across the Cenjiawan Platform. Resulting landscapes should have had an impact on the formation processes of Early Pleistocene sites

across the area, which highlights the significance of considering the geomorphological background to reach a better understanding of the post-depositional disturbance in the Nihewan Basin archaeological assemblages.

Despite the wealth of Early Pleistocene sites in the Nihewan Basin, systematic analyses of assemblage formation processes are still rare (but see Jia *et al.*, 2019; Pei *et al.*, 2016, 2017) and sustained efforts are required to gain a more accurate picture of settlement patterns and hominin adaptations during the Early Pleistocene of northern China.

Author's contributions—DDM: Data curation, formal analysis, writing – original draft, writing – review and editing. SWP: Conceptualisation, funding acquisition, methodology, writing – review and editing. FX: Investigation, resources and supervision. IDLT: Conceptualisation, funding acquisition, methodology, writing – review and editing. XD: Data curation. ZY: Data curation. All authors have contributed to the article and approved the submitted version.

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Conflict of interest statement—The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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